MODELLING 3D MECHANICAL INTERFACES WITH CONTINUUM ELEMENTS

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Abstract. *This document presents preliminary results of FEM-numerical analysis of soil-reinforcement pullout tests. The numerical model has been developed with CODE_BRIGHT and assuming the interfaces as continuum materials. The results of the preliminary parametric analyses described herein provide useful information on the shear behavior modeling of soil-reinforcement strip interfaces under working stress conditions.*

1 INTRODUCTION

Accurate design of reinforced soil-retaining walls requires knowledge of the actual interface shear behavior of the reinforcement elements. Typically, these types of structure operate under working stress conditions (i.e. far away from failure), so they do not generate enough strain to fully develop soil-reinforcement interface strength. Nevertheless, interfaces must have adequate stiffness and shear strength. Therefore, pullout tests are particularly useful to examine interface behavior and to quantify interface stiffness and strength. These parameters allow reinforcement design optimization to be carried out and/or to determine an adequate number of reinforcement elements to ensure safety.

Several FE models have been developed to analyze these types of structures and interface behavior [1]. For steel reinforcement and also rough polymeric strips, interfaces are assumed to be rigid (i.e. perfectly bonded to the surrounding soil). This approach is consistent with back-calculated pullout shear resistance reported in the literature [2].

2 NUMERICAL MODEL OF PULLOUT

2.1 Model features: materials, properties and boundary conditions

Figure 1 shows the 3D numerical model mesh geometry developed to analyze the pullout behavior of a steel strip placed in a box with appropriate box dimensions to minimize boundary effects. The reinforcement has typical strip dimensions. The model has 1652 nodes corresponding to 1350 hexahedral elements. As can be observed, the reinforcement-backfill interface has been modeled assuming a certain thickness of continuum elements.

The calculation process takes two stages: The first one corresponds to an initial equilibrium state (steps from 0 to 10, taking one day), and the application of the pullout load (steps from 10 to 11, taking another day). The pullout has been modeled by prescribing a constant velocity-displacement to the front of the reinforcement strip at the beginning of the second stage (i.e. step 10), which generates about 20 cm of pullout displacement at the end of the stage (i.e. at the end of the step 11). No external surcharge pressures have been considered in the analyses.

With respect to the remaining boundary conditions, displacements in the orthogonal directions are not allowed, with the exception of the top-horizontal surface and the interface areas at front and back surfaces (no prescribed conditions), and the reinforcement (which has the prescribed pullout displacement at the front, and free-end displacement at the back).

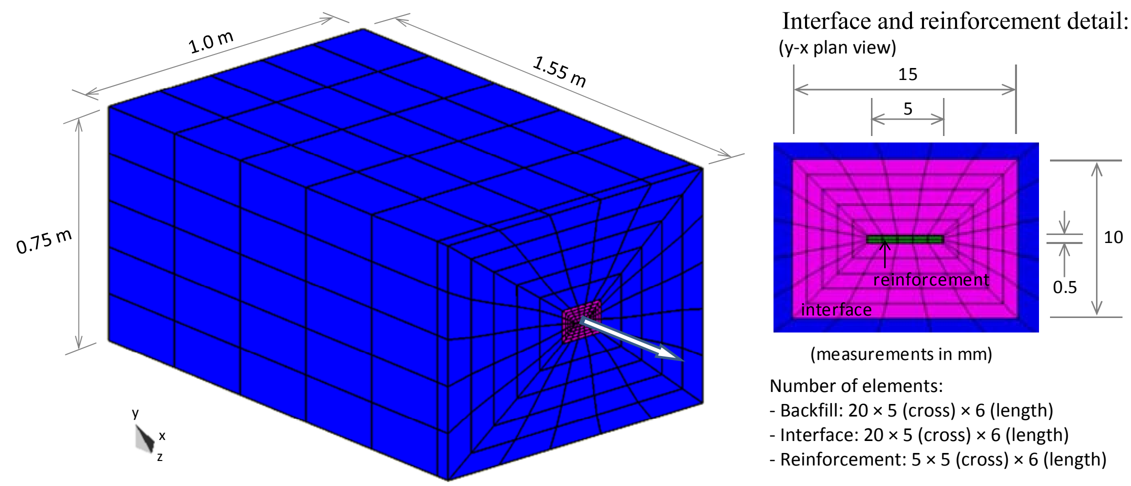

Figure 1: FE - 3D model mesh and geometry dimensions

Table 1 presents the constitutive model material parameters. As can be observed, the reinforcement material has been modeled as a linear elastic material, which is a good assumption for steel reinforcements (e.g. steel strips or ladders). Soil materials (i.e. the backfill soil and the soil-reinforcement interface) have been modeled with a linear elastic stiffness (Young's modulus and Poisson's ratio parameters) plus a visco-plastic law at strength-failure, which is controlled by the cohesion, friction angle and dilatancy angle. A suitably low viscosity value has been selected so that viscous effects do not influence numerical outcomes.

	Materials					
Parameters	Reinforcement	Backfill		Interface		Units
Solid phase density	75	27		27		kN/m^3
Porosity, n	0.001	0.3		0.3		-
Young's modulus, E	210 000	20		20		MPa
Poisson's ratio, ν	0.3	0.3	0.05	0.3	0.49	-
Cohesion, c	-	0.001		0.001		MPa
Friction angle, ϕ	-	45	45 (rigid)	31 (= 0.6ϕ)	17 (= 0.3ϕ)	degrees
Dilatancy angle, ψ	-	15	15	1	0	degrees

Table 1: Constitutive model material parameters

2.2 Results

Figures 2 and 3 present the results of the base case, which corresponds to a rigid interface case and ν = 0.3 (i.e. same properties as the surrounding material). As can be observed in Figure 2, pullout displacements generate significant vertical displacements due to dilatancy effects. This effect becomes more significant at both edges of the reinforcement due to the boundary conditions of prescribed displacements, but it is not caused by the axial strains of the reinforcement (which can be assumed as inextensible). Results of the stresses and strains of the backfill and interface at different reinforcement length locations can be observed in Figure 3. Vertical stresses are also the result of dilatancy behavior, increasing in value around the vertical sides of the reinforcement strip with respect to soil overburden pressure.

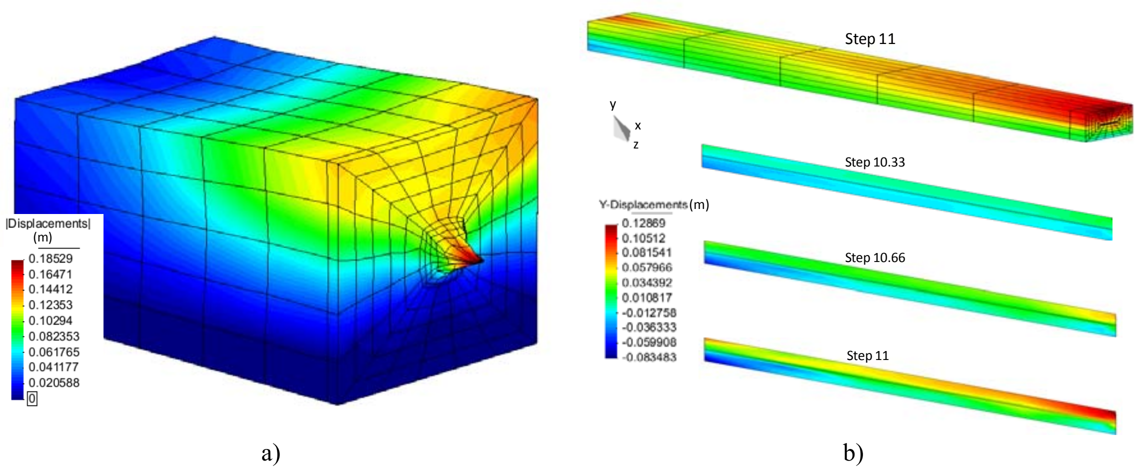

Figure 2: Rigid interface case with ν = 0.3: Total displacements and deformed mesh (a) and vertical displacements results (b) with their evolution in time on interface cross-length-section

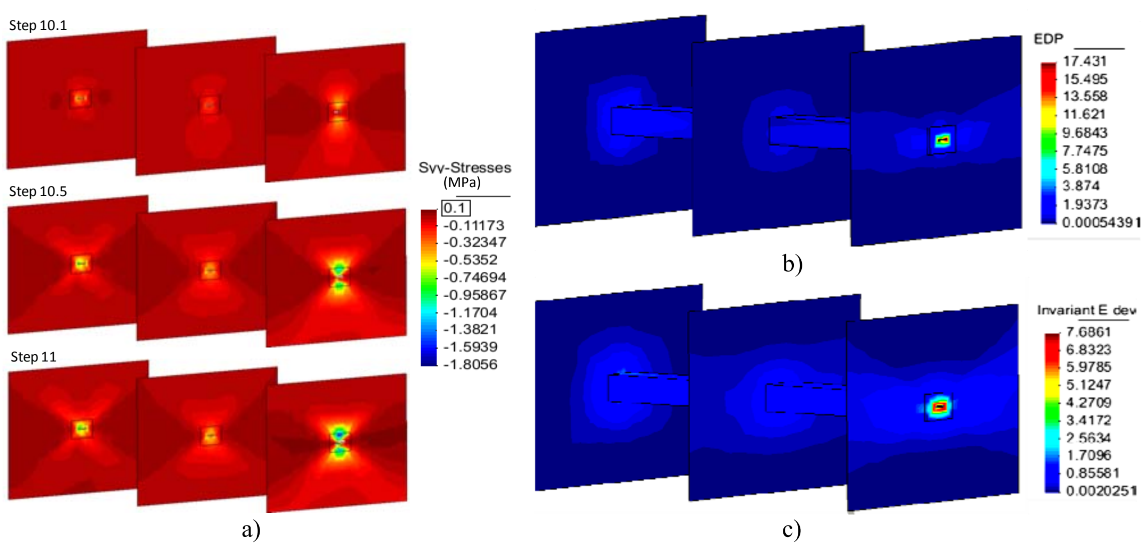

Figure 3: Rigid interface case with ν = 0.3: (a) vertical stress, (b) plastic shear strains and (c) total shear strains, over three cross-lateral-sections of backfill and interface materials

Figure 4 presents the results of the pullout axial stress at the edge of the reinforcement with respect to axial displacement, for the three cases of interface Poisson's ratio (0.05 − 0.3 − 0.49), for each case of interface strength reduction (rigid − 0.6ϕ − 0.3ϕ). Poisson's ratio appears to have little influence on interface performance for the assumed conditions. Figure 5 shows the total shear strains according to the interface strength and ν = 0.3. As can be observed, the less the interface strength (e.g. 0.3ϕ case), the more clearly defined the shear zones (i.e. failure surfaces) that are generated due to the pullout.

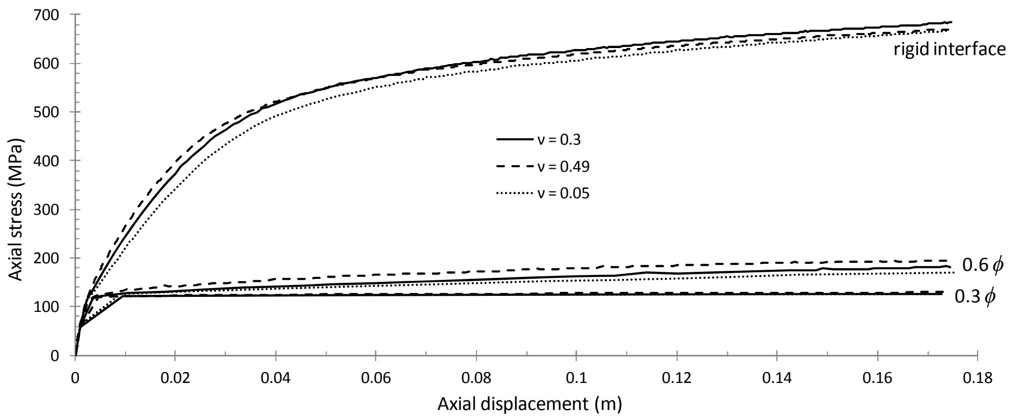

Figure 4: Axial stress-displacement responses

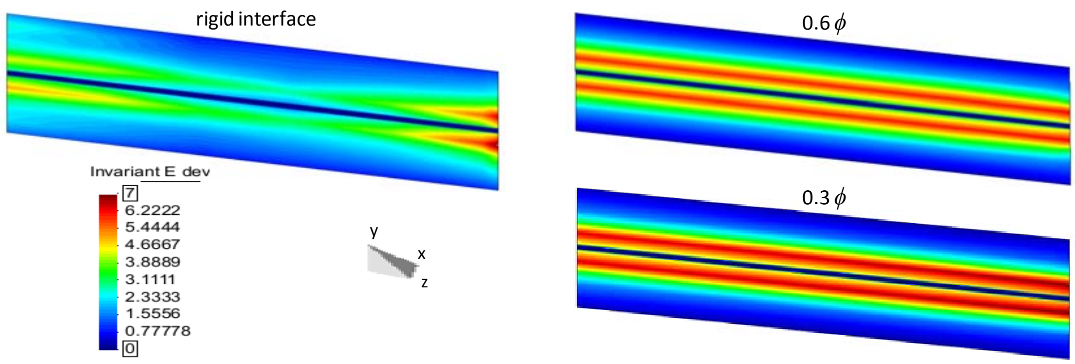

Figure 5: Total shear strains at interface due to pullout. Failure surface generation

3 CONCLUSIONS

- The numerical 3D model for steel reinforcement pullout appears promising for future analyses.
- Soil behavior trends observed are in agreement with experimental data.

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